

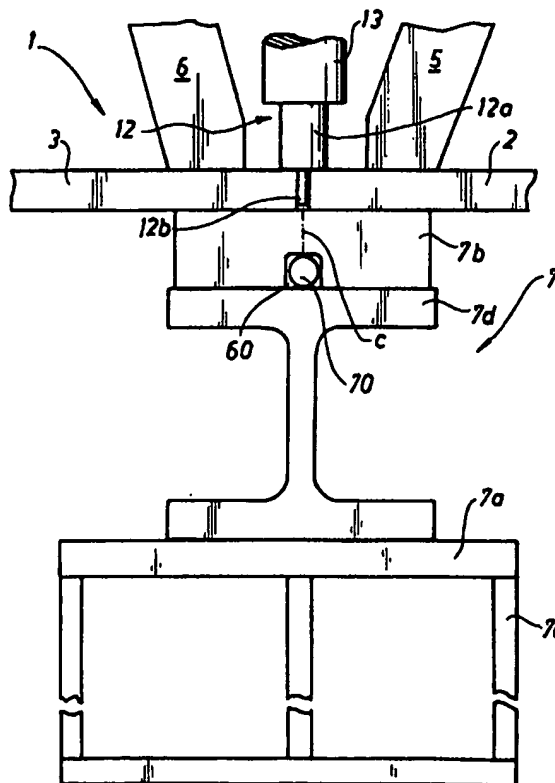


## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<b>(51) International Patent Classification <sup>6</sup> :</b> <b>B23K 20/12</b>	<b>A1</b>	<b>(11) International Publication Number:</b> <b>WO 98/45080</b> <b>(43) International Publication Date:</b> 15 October 1998 (15.10.98)
<b>(21) International Application Number:</b> PCT/SE98/00613 <b>(22) International Filing Date:</b> 3 April 1998 (03.04.98)  <b>(30) Priority Data:</b> 9701265-2                      4 April 1997 (04.04.97)                      SE  <b>(71) Applicant (for all designated States except US):</b> ESAB AB [SE/SE]; P.O. Box 8004, S-402 77 Göteborg (SE).  <b>(72) Inventors; and</b> <b>(75) Inventors/Applicants (for US only):</b> KNIPSTRÖM, Karl, Erik [SE/SE]; Lingonstigen 5, S-695 30 Laxå (SE). MALM, Anders [SE/SE]; Hökstigen 9, S-695 30 Laxå (SE).  <b>(74) Agent:</b> AWAPATENT AB; P.O. Box 113 94, S-404 28 Göteborg (SE).		<b>(81) Designated States:</b> AL, AM, AT, AT (Utility model), AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, CZ (Utility model), DE, DE (Utility model), DK, DK (Utility model), EE, EE (Utility model), ES, FI, FI (Utility model), GB, GE, GH, GM, GW, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SK (Utility model), SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).  <b>Published</b> <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i> <i>In English translation (filed in Swedish).</i>

**(54) Title:** METHOD AND APPARATUS FOR FRICTION STIR WELDING**(57) Abstract**

The invention concerns a friction stir welding method according to which the workpieces (2, 3) to be welded are positioned on a work-table (7) and by means of clamping means (5, 6) clamped to one another and/or to the work-table during the welding. A rotating welding means (12, 13) is arranged to move along a joint between the workpieces while being pressed against said workpieces during the welding. Additional heat is supplied to the joint prior to and/or during the welding operation, in excess of the frictional heat generated in the joint from the rotation of the welding means and of any other heat that may be supplied to the joint in any other manner by the welding means. The invention likewise concerns an apparatus for friction stir welding, comprising a heating element (70) for supply of additional heat to the joint prior to and/or during the welding operation, in excess of the frictional heat generated in the joint from the rotation of the welding means and of any other heat that may be supplied to the joint in any other manner by the welding means.



**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakhstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

METHOD AND APPARATUS FOR FRICTION STIR WELDING

The present invention relates to a friction stir welding method according to which the workpieces to be welded are positioned on a work-table and by means of clamping means clamped to one another and/or to the work-  
5 table and according to which a rotating welding means is arranged to move along a joint between the workpieces while being pressed against said workpieces during the welding.

The present invention likewise relates to an  
10 apparatus for friction stir welding, comprising a work-table supporting the workpieces to be welded, at least one clamping means for clamping the workpieces to one another and/or to the work-table, and a welding means adapted to be advanced along a joint between the work-  
15 pieces while being pressed against said workpieces during the welding.

The definition friction stir welding designates a welding method according to which the workpieces to be joined together are plasticized along their joint line by  
20 supply of frictional heat from a rotating welding probe, said probe being moved along the joint between the workpieces while at the same time being pressed against the work-pieces. As described in W093/10935 and W095/26254 the welding probe should be manufactured from a material  
25 that is harder than that of the workpieces, and during the welding operation the workpieces should be securely fixed relative to one another and to the work-table. In this respect this technique differs from that of conventional friction welding according to which the frictional heat is generated by the relative motion of the  
30 workpieces as they are being pressed together, i.e. the frictional heat is generated only by the two components to be joined together. This friction stir welding technique according to the above-mentioned publications

is used for the welding of different materials, such as plastics, metals, etcetera in various fields of application, for example to join workpieces together, to repair cracks in a workpiece, and so on. The design of the welding probe is conditioned e.g. by the material to be welded and by the intended application.

In gas metal arc welding and particularly in submerged arc welding when the molten pools generally are of considerable dimensions, a backing means is often used, i.e. a backing bar which is pressed against the back of the joint during the welding operation in order to support the edges of the joint and to prevent the molten pool from escaping as the complete weld penetration stage is reached. In constructing the backing means thermal considerations are to a large extent decisive in the choice of the backing means material, particularly in the case of welding of aluminium. The cooling effect on the joint from the backing means must not be too powerful.

Similarly, backing means are likewise used in complete penetrating welding in connection with friction stir welding. In this case, the backing means serves as a mechanical support and shapes the lower face of the joint. Also in this case the backing means may be formed with a thermal barrier against a subjacent backing bar in order better to take advantage of the friction heat generated in the welding process.

One of the problems encountered in friction stir welding of hard-to-weld materials, such as aluminium alloyed with magnesium, with lithium or with copper, is that the forces deployed during the welding operation are of such a magnitude as to cause the welding probe to break after a comparatively short period of welding, as a result of fatigue. This is true particularly of workpieces that have a thickness exceeding 5 mm.

Another problem is the generation of short but deep cracks in the surface of the backing means, particularly

in the transverse direction of the latter, due to thermal fatigue. Because the joint, owing to the plasticisation thereof during the welding operation, will adopt the appearance of the backing means surface, these cracks  
5 will manifest themselves as protrusions on the lower face of the joint, and as a result the joint will be unacceptable.

A further problem is that the frictional heat generated in hard-to-weld materials may be insufficient, and  
10 that consequently complete weld penetration is not achieved, or that lack of fusion will occur.

One object of the present invention therefore is to provide a method and an apparatus for friction stir welding by means of which it becomes possible to substantially prolong the serviceable life of said welding  
15 probe. It is likewise desirable to simultaneously increase the quality of the formed joint, primarily by securing safe weld penetration and complete fusion vis à vis the base material, and in addition thereto increase  
20 productivity.

This object is achieved in accordance with the present invention by means of a friction stir welding method of the kind defined in the introduction, which method is characterised in that additional heat is  
25 supplied to the joint prior to and/or during the welding operation, in excess of the frictional heat generated in the joint from the rotation of the welding means and of any other heat that may be supplied to the joint in any other manner by the welding means, the start of the  
30 welding operation proper considered to be the instant when the welding probe is lowered into the joint.

In order to achieve said object, the present invention also provides an apparatus of the kind outlined in the introduction for friction stir welding, which apparatus  
35 is characterised by a heating means for supply of additional heat to the joint prior to and/or during the welding operation, in excess of the frictional heat

generated in the joint from the rotation of the welding means and of any other heat that may be supplied to the joint in any other manner by the welding means.

Due to the supply of additional heat to the joint  
5 between the workpieces in excess of the frictional heat generated through the rotation of the welding means and any other heat that may be supplied to the joint by the welding means in any other manner, the serviceable life of the welding probe is prolonged considerably. In cases  
10 when the joint is backed up by means of a subjacent backing means, cracking of the latter is also prevented, if heat is supplied to the joint by way of the backing means. The difference is pronounced and is a prerequisite for the welding of for instance several aluminium alloys  
15 with acceptable economy. In addition, higher welding quality is obtained because of improved penetration and safer bonding against the base material, and it also becomes possible to increase the welding speed with consequential higher productivity.

20 Advantageous modified varieties of this method and this apparatus will be defined in the dependent claims.

The invention will be described in the following in closer detail with reference to the accompanying drawing figure illustrating one embodiment of the apparatus in  
25 accordance with the present invention.

The apparatus 1 shown in the drawing figure is intended for welding together two workpieces 2, 3, the latter being e.g. extruded aluminium profile sections.

During the welding operation, the workpieces 2, 3  
30 are secured to the work-table 7 by clamping means 5 and 6, respectively. The clamping means 5 and 6, respectively, may consist of a compression cylinder. The present work-table is a horizontal machine table 7a to which a backing means 7b is stationarily secured by means  
35 of a backing bar 7d in the shape of an I-beam and which is supported by a stationary, rigid frame 7c. The backing means 7b is formed with a groove 60 extending in the

longitudinal direction of the support, said groove having received therein a heating coil in the form of a heating cable 70.

The joint between the workpieces 2, 3 is placed in alignment with the centre line of the backing means. The backing means backs up also the edges of the joint and prevents the plasticized material from flowing away at the attainment of complete weld penetration.

Welding is performed by means of a welding means in the form of a welding probe 12 and a rotating spindle 13. The welding probe consists of a cylindrical body 12a having attached thereto a cylindrical pin 12b the circumference of which is smaller than that of the probe body. Owing to this arrangement, the lower part of the cylindrical body will project beyond the upper part of the pin. In the following, the lower part of the body will be referred to as the shoulder of the body, and as appears from the drawing figure the shoulder abuts against the upper faces of the workpieces 2, 3 in the normal position of the welding probe. The welding probe body and pin could be configured for example in conformity with any one of the embodiments shown in WO93/10935 or in WO95/26254. The upper part of the body 12a is connected to the rotating spindle 13 which is driven by a drive unit, not shown, such as a drive motor.

The workpieces 2, 3 are first secured in the apparatus 1 by means of the clamping means 5, 6, care being taken that the air gap, i.e. the joint, between the facing end edges of the profile sections does not exceed the dimensions that are liable to cause a deficient weld to form. As appears from the drawing figure, the gap is placed in alignment with the centre line c of the backing means 7b. The backing means is then pre-heated by means of the built-in heating cable 70, until the temperature of the backing means is in the range of 150-250°C. This temperature range is detected by traditional means, for instance by a temperature sensor, not shown. Following

the pre-heating of the backing means, and thus of the joint, the welding operation is initiated by the welding probe being made to rotate at a certain speed while at the same time being advanced along the gap at a predetermined speed. As described initially, the end edges of the profile sections will become plasticized by the frictional heat generated during this process.

The resulting welded joint, when solidified, is a homogeneous, high-strength joint.

It should be appreciated that the invention is not limited to the above embodiments but could be modified in a number of different ways within the scope of the appended claims. For example the backing means 7b could be heated by a heating fluid supplied to the groove 60 or by indirect supply of electricity instead of by means of a heating cable 70 built into the groove. Instead of heating the joint via the backing means, the joint could be heated by a heating element, such as a gas burner positioned underneath the joint or in contact with the sides of the joint. Induction heating is another possible method of supplying the additional heat. The apparatus could of course be used for welding together workpieces of other metals or metal alloys than aluminium, such as e.g. titanium or steel. When the apparatus is used to weld together titanium or steel workpieces the backing means should be heated to temperatures in the range of 500-1000°C.

## CLAIMS

1. A friction stir welding method according to which the workpieces (2,3) to be welded are positioned on a work-table (7) and by means of clamping means (5,6) clamped to one another and/or to the work-table and according to which a rotating welding means (12, 13) is arranged to move along a joint between the workpieces while being pressed against said workpieces during the welding, c h a r a c t e r i s e d in that additional heat is supplied to the joint prior to and/or during the welding operation, in excess of the frictional heat generated in the joint from the rotation of the welding means and of any other heat that may be supplied to the joint in any other manner by the welding means.

2. A method as claimed in claim 1, c h a r a c t e r i s e d by pre-heating the joint to a maximum of 250°C below the fusion temperature of the material of the joint.

3. A method as claimed in claim 1 or 2, c h a r a c t e r i s e d in that the joint is heated by a heating element positioned underneath the joint.

4. A method as claimed in any one of the preceding claims, c h a r a c t e r i s e d in that the joint is supported by a subjacent backing means (7b) which is pre-heated to a temperature in excess of 100°C.

5. A method as claimed in claim 4, c h a r a c t e r i s e d in that the backing means is heated to a temperature in the range of 150-250°C.

6. A method as claimed in claim 4, c h a r a c t e r i s e d in that the backing means is heated to a temperature in the range of 500-1000°C.

7. A method as claimed in claims 4, 5 or 6, c h a r a c t e r i s e d in that the backing means (7b) is heated by a heating coil (70) built into backing means.

8. An apparatus (1) for friction stir welding, comprising a work-table (7) supporting the workpieces (2,3) to be welded, at least one clamping means (5,6) for clamping the workpieces to one another and/or to the work-table, and a welding means (12, 13) adapted to be advanced along a joint between the workpieces while being pressed against said workpieces during the welding, characterised by a heating element (70) for supply of additional heat to the joint prior to and/or during the welding operation, in excess of the frictional heat generated in the joint from the rotation of the welding means and of any other heat that may be supplied to the joint in any other manner by the welding means.

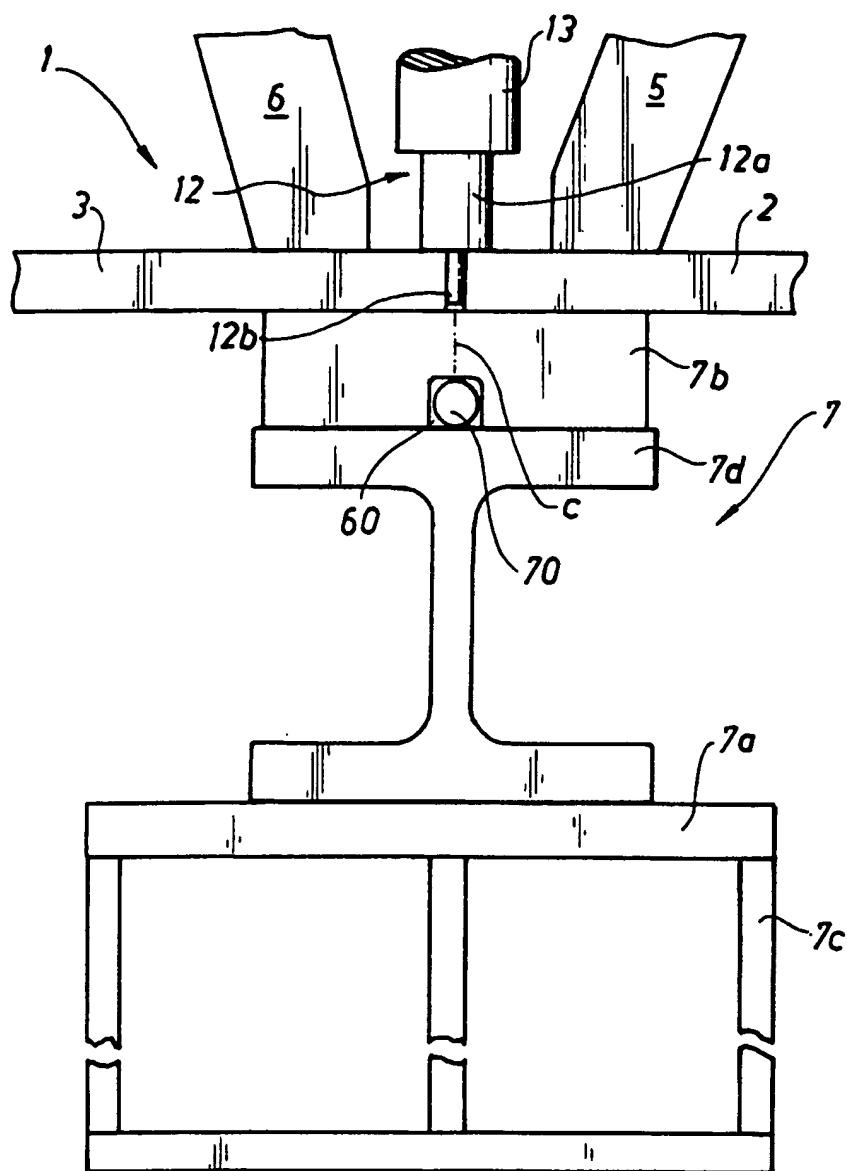
9. An apparatus as claimed in claim 8, characterised in that it comprises a heating element positioned underneath the joint.

10. An apparatus as claimed in claim 8 or 9, characterised by a backing means (7b) positioned underneath the joint.

11. An apparatus as claimed in claim 10, characterised in that the backing means (7b) is adapted to be heated by the heating element (70).

12. An apparatus as claimed in claim 11, characterised in that the heating element is a heating coil (70) built into the backing means (7b).

1/1



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 98/00613

## A. CLASSIFICATION OF SUBJECT MATTER

IPC6: B23K 20/12

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: B23K, B29C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

ORBIT: WELD; EPO: WPI, PAJ

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 9310935 A1 (THE WELDING INSTITUTE), 10 June 1993 (10.06.93), page 10, column 13 - line 20  --	1-12
A	WO 9526254 A1 (NORSK HYDRO A.S), 5 October 1995 (05.10.95)  -- -----	1-12



Further documents are listed in the continuation of Box C.



See patent family annex.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&amp;" document member of the same patent family

Date of the actual completion of the international search

12 August 1998

Date of mailing of the international search report

13 -08- 1998

Name and mailing address of the ISA/

Swedish Patent Office

Box 5055, S-102 42 STOCKHOLM

Facsimile No. +46 8 666 02 86

Authorized officer

Bertil Dahl

Telephone No. +46 8 782 25 00

**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

27/07/98

International application No.

PCT/SE 98/00613

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9310935 A1	10/06/93	AU 658950 B	04/05/95
		AU 662310 B	31/08/95
		AU 1016495 A	30/03/95
		AU 2952892 A	28/06/93
		CA 2123097 A	10/06/93
		DE 69205991 D,T	11/04/96
		EP 0615480 A,B	21/09/94
		SE 0615480 T3	
		EP 0653265 A	17/05/95
		JP 2712838 B	16/02/98
		JP 7505090 T	08/06/95
		US 5460317 A,B	24/10/95
WO 9526254 A1	05/10/95	AU 676424 B	06/03/97
		AU 1592395 A	17/10/95
		CA 2182719 A	05/10/95
		CN 1144499 A	05/03/97
		CZ 9602586 A	16/04/97
		DE 69502716 D	00/00/00
		EP 0752926 A,B	15/01/97
		FI 963889 A	27/09/96
		JP 9508073 T	19/08/97
		NO 941144 D	00/00/00
		NO 942790 D	00/00/00
		NO 964115 A	27/09/96
		PL 316614 A	20/01/97